Applications of Deployable Telescopes for Earth-Observing Lidar

Syed Ismail
NASA Langley Research Center
Science Directorate, Hampton, Virginia 23681

Lee. D. Peterson, Jason. D. Hinkle
University of Colorado, Boulder, Colorado 80309-0429

Edward Friedman
Boeing-SVS, Boulder, Colorado

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Earth science focus areas of NASA's Earth-Sun System

Climate | Carbon | Surface | Atmosphere | Weather | Water

'NASA's goal in Earth science is to observe, understand, and model the Earth system to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. We do so by characterizing, understanding, and predicting change in major Earth system processes and by linking our models of these processes together in an increasingly integrated way. '

- **Active remote sensing by lidar has application in all Earth science focus areas**

- **Deployable telescope technology development enables space-based lidar remote sensing in all Earth science focus areas**

<u>Development of Deployable Telescope Technology</u>

Background:

- NASA Langley and U. Colorado initiated a program to develop deployable lidar receiver for atmospheric science applications in the 1990's

- Developed design, and hardware in cooperation with Composite Optics, Inc.

- Hinges, latches and a single pedal of a 2.5 m diameter were built

- Provided 50 times increase in relative overall stability over then existing technology

NASA ESTO, ACT Program for Deployable Optics Modeling Experiments (DOME) -- Objective:

Experimental Verification to advance precision deployment technology to flight readiness

DOME objectives and requirements

Three primary elements of DOME:

a. Precision latching design to improve precision error (by design analysis and not trial and error)

- Design new latch with micron level intrinsic repeatability, high stiffness, and low hysteresis

b. Sub-system verification of deployment precision and stability

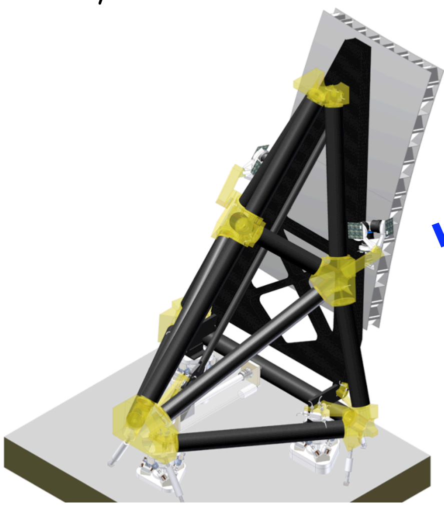
- Develop and test a single pedal lidar test article in multiple gravity orientations

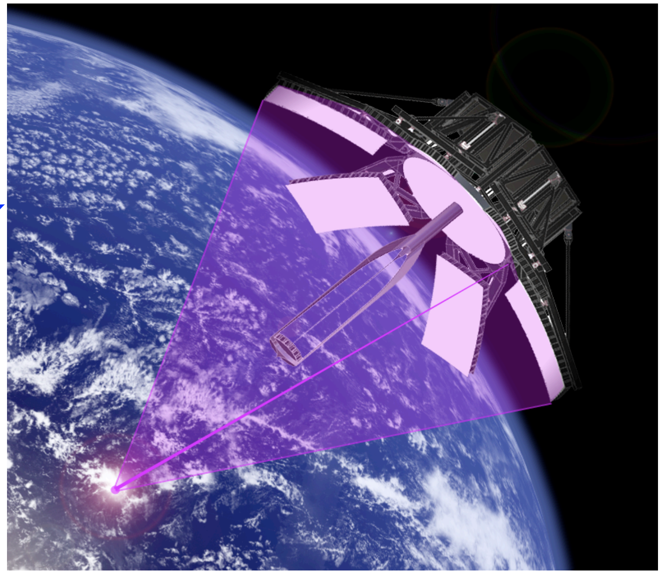
c. Theoretical modeling

- Develop model in conjunction with experiments for specifying requirements and future lidar requirements

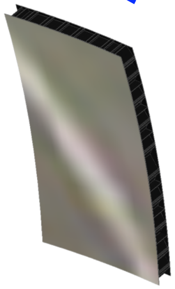
DOME Project Develops Component Technology Leading to a Flight-Ready Instrument Concept

Sub-System Verification

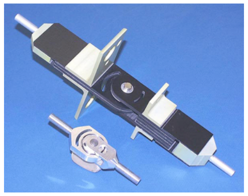




Flight-Ready Concept



Low-Cost, Low-Mass Mirror Segment



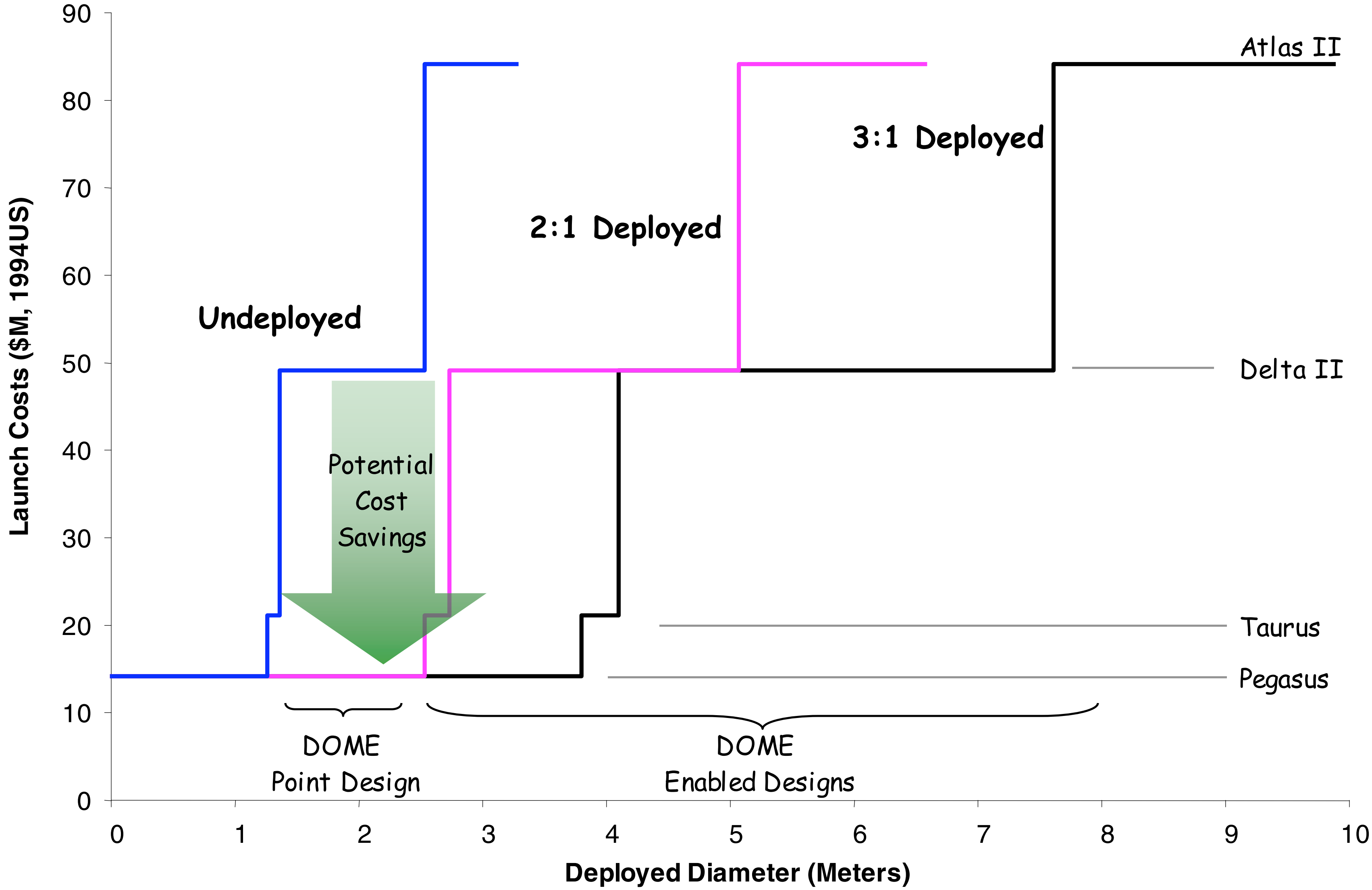
Precision Mechanisms and Structures

- Low cost deployed lidar telescope mirror
  - Pegasus-size package (2:1 deployed diameter)
  - Equivalent to Delta-II-size undeployed mirror

- Eliminates need for figure control of deployed petals
  - 50:1 improvement in structural performance through deployed depth reaction structure

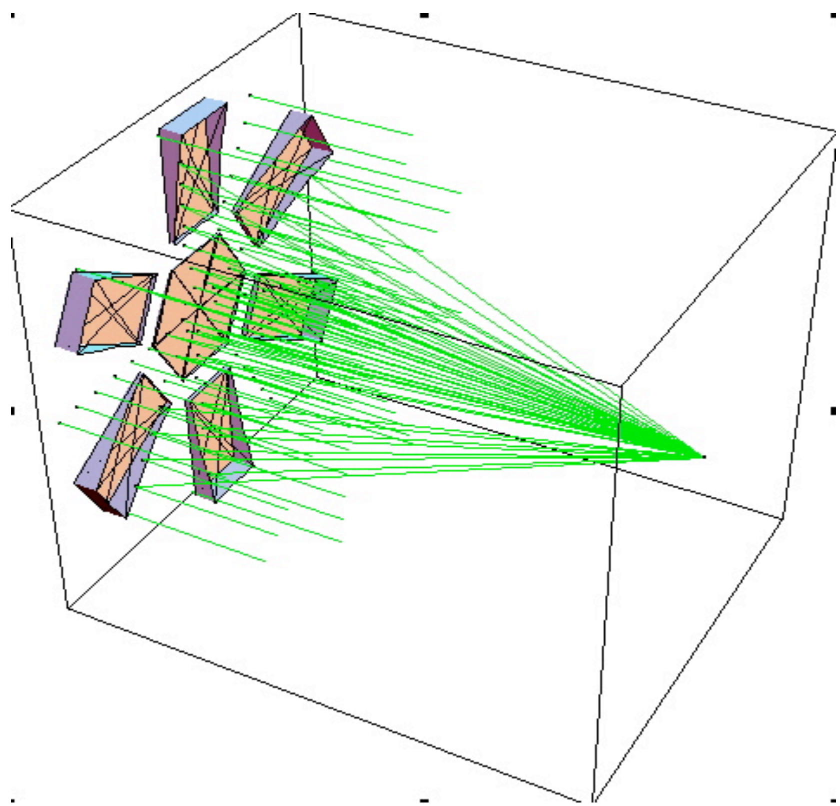
- Mitigates higher power laser issues:
  - 4-10 times improvement in sensitivity
  - Power, size, cost, and risk
  - Heat dissipation
  - Eye-safety

Deployment Substantially Reduces Launch Costs



Cost and Diameter Data Source: http://www.jsc.nasa.gov/bu2/ELV_US.html (2003-09-09)

Ray Trace for the Segmented Aperture



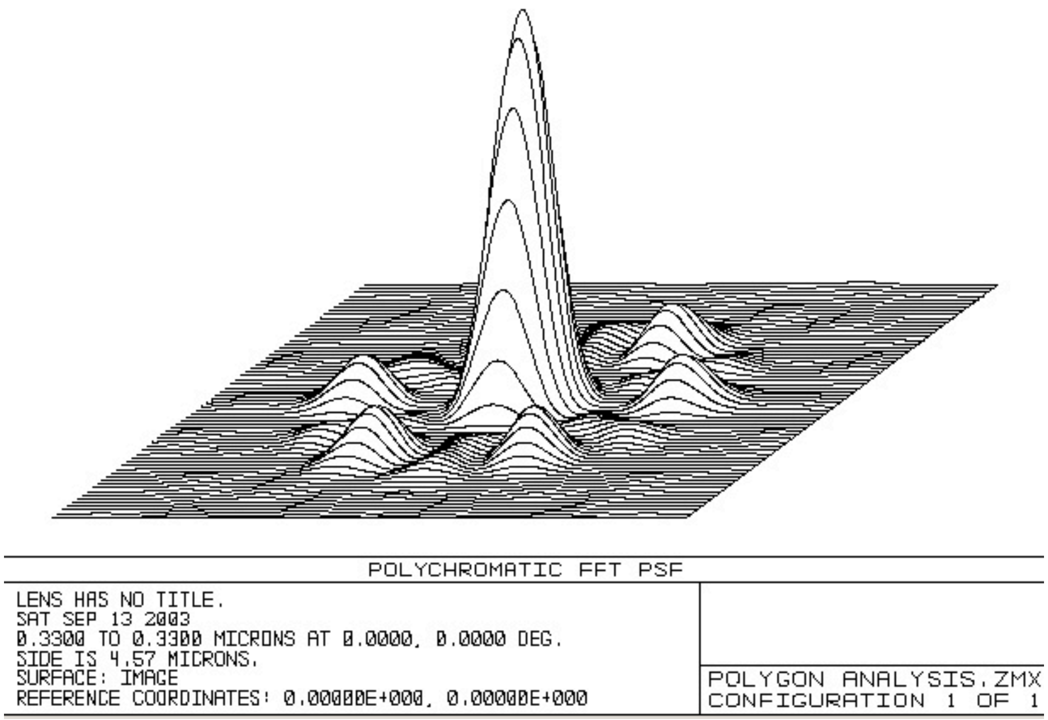
Optical ray tracing analysis conducted by Boeing-SVS to optical design and tolerance analysis by including on-orbit disturbances

•Explored tolerance analysis for tip, tilt and piston for primary mirror segments for a range of f/numbers and primary mirror shapes (spherical and parabolic)

•Developed 4 mirror telescope designs for systems with spherical primary mirrors

- **- Produced optimized designs by introducing aspheric secondary mirror**

Diffractive Propagation of the Point Spread Function for the Segmented Aperture



- **Developed diffraction analysis of the point spread function of various configuration of the telescope**
- **Using the diffraction analysis, computed the Strehl ratio of the telescope as a function of field angle**
  - **-Sensitivity of Strehl ratio to motions of primary mirror segments**
- **Radial tilt of a petal can be as large as 1.9 waves for S = 0.8**
- **Azimuthal tilt of about 4.2 waves is allowed for a single plate**
- **In all cases, the field of view of should be limited to <0.4 degrees.**

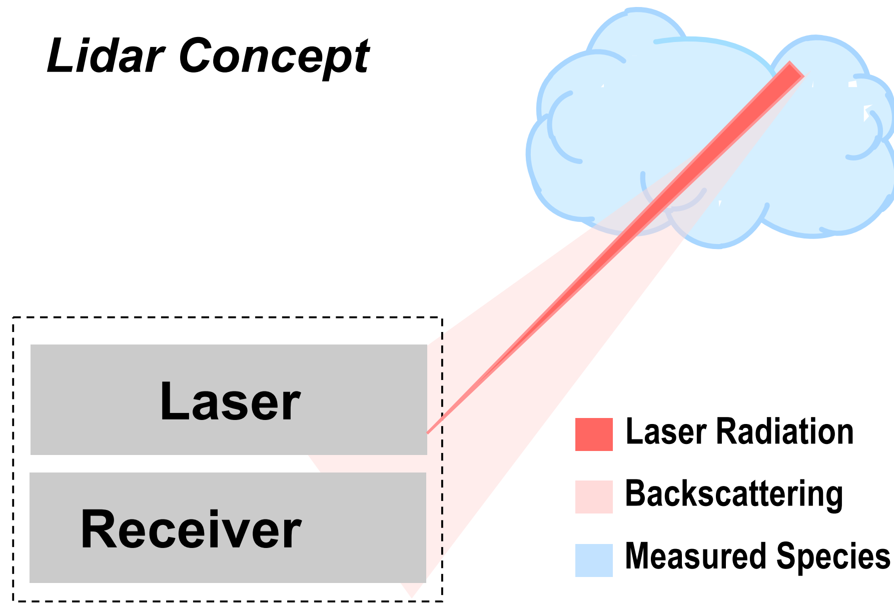
For most of lidar applications (the direct detection lidar) the telescope is used as a 'light bucket' and aberrations are not a problem.

Lidar Characteristics

Lidar capabilities:

- High spatial resolution
- High spectral resolution
- High temporal resolution
- Day background rejection
- Choice of wavelength
- No interference from other species
- Direct inversion

Lidar Concept

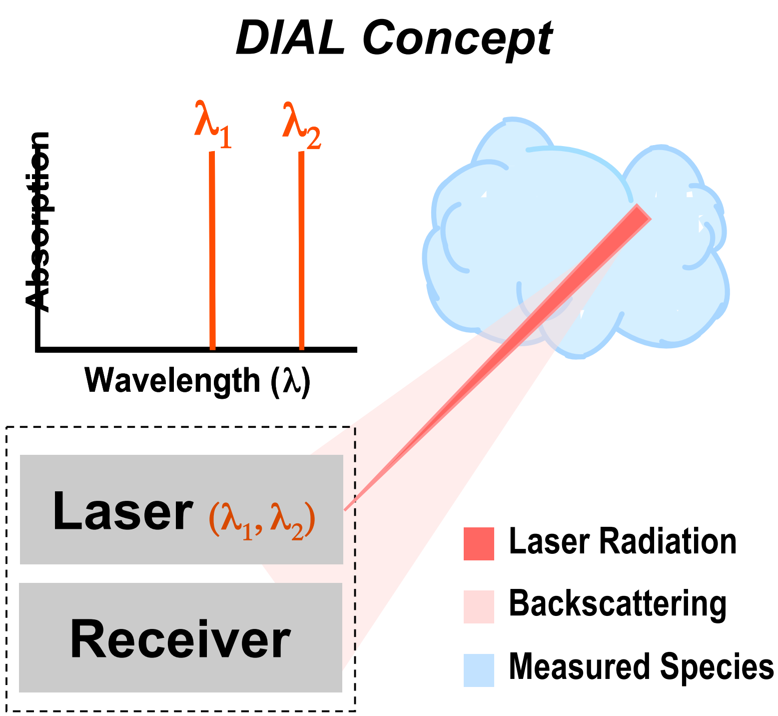


Four Lidar Types:

Backscatter (aerosol and cloud) lidar
Surface mapping lidar
Differential absorption lidar (DIAL)
Doppler (wind) lidar

Lidar best suited to provide vertical profile information

Differential Absorption Lidar (DIAL) Technique and Advantages



Advantages:

•High vertical and horizontal resolution

•DIAL data permit direct inversion and absolute concentration measurements

•Simultaneous species and aerosol profiles, and cloud distributions

•Day and night coverage and no dependence on external radiation

•DIAL technique suitable for Atmospheric O_3, H_2O, and CO_2 measurements

•Large collection area receivers needed to enable DIAL measurements from space

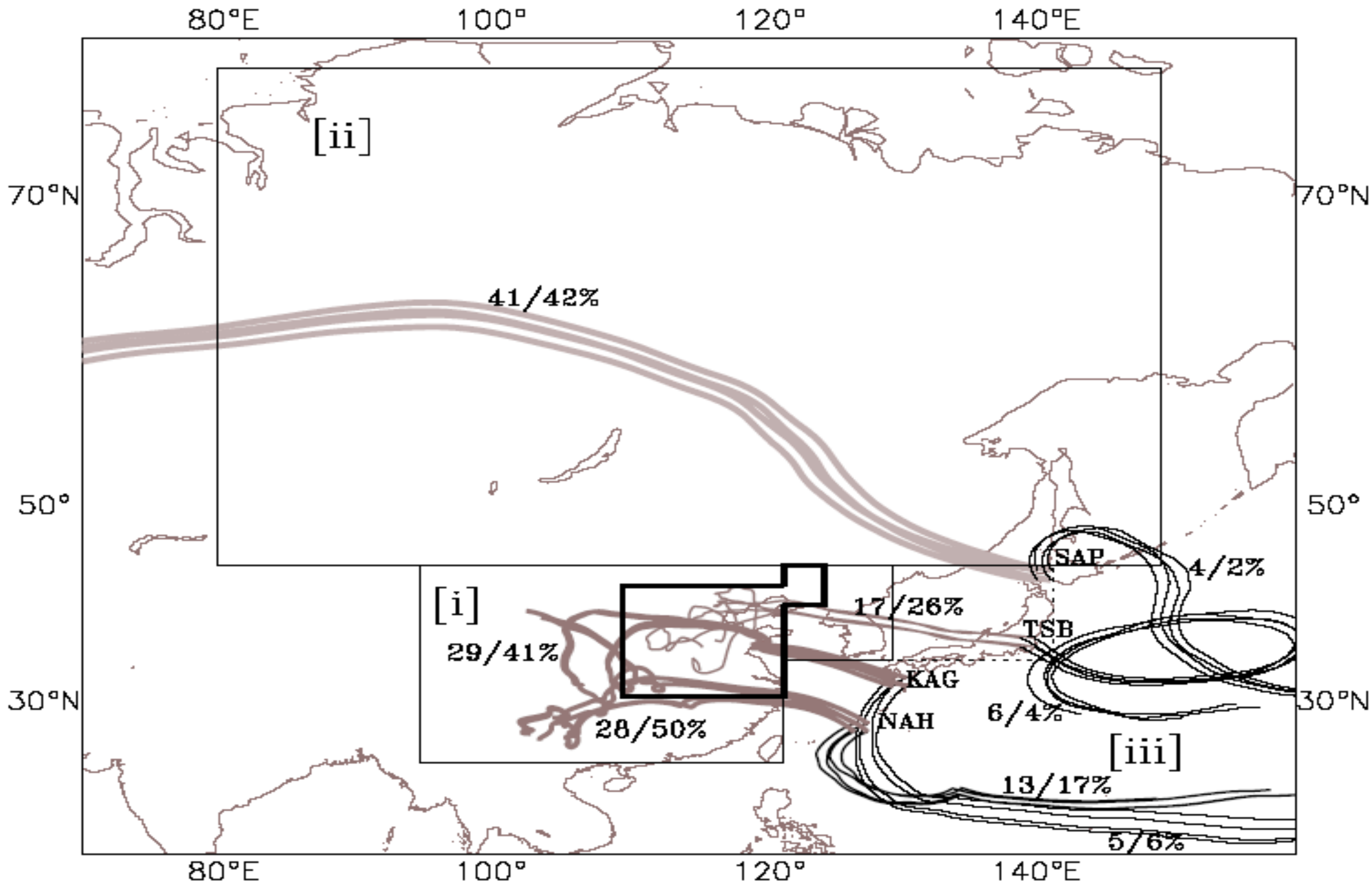
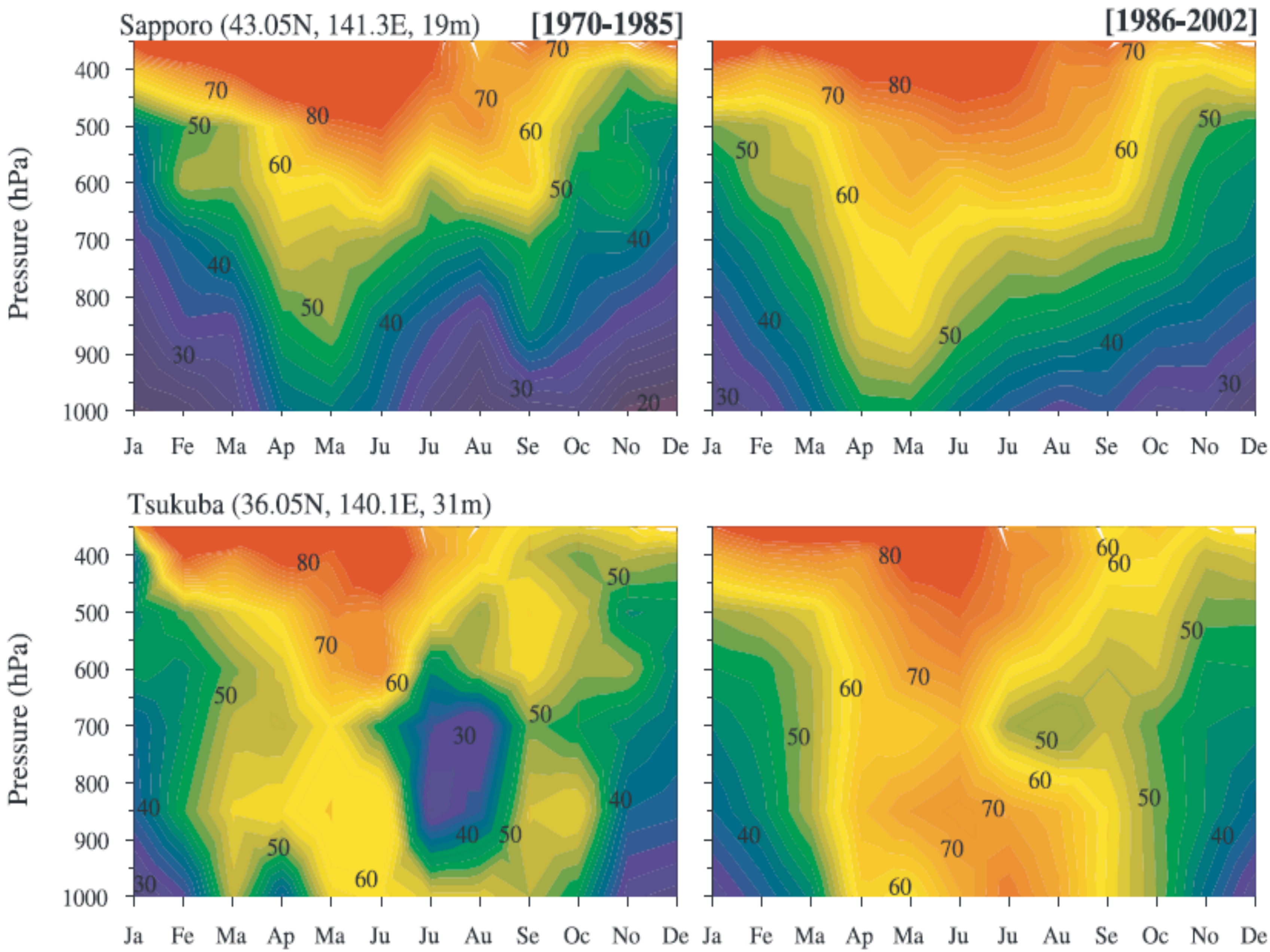


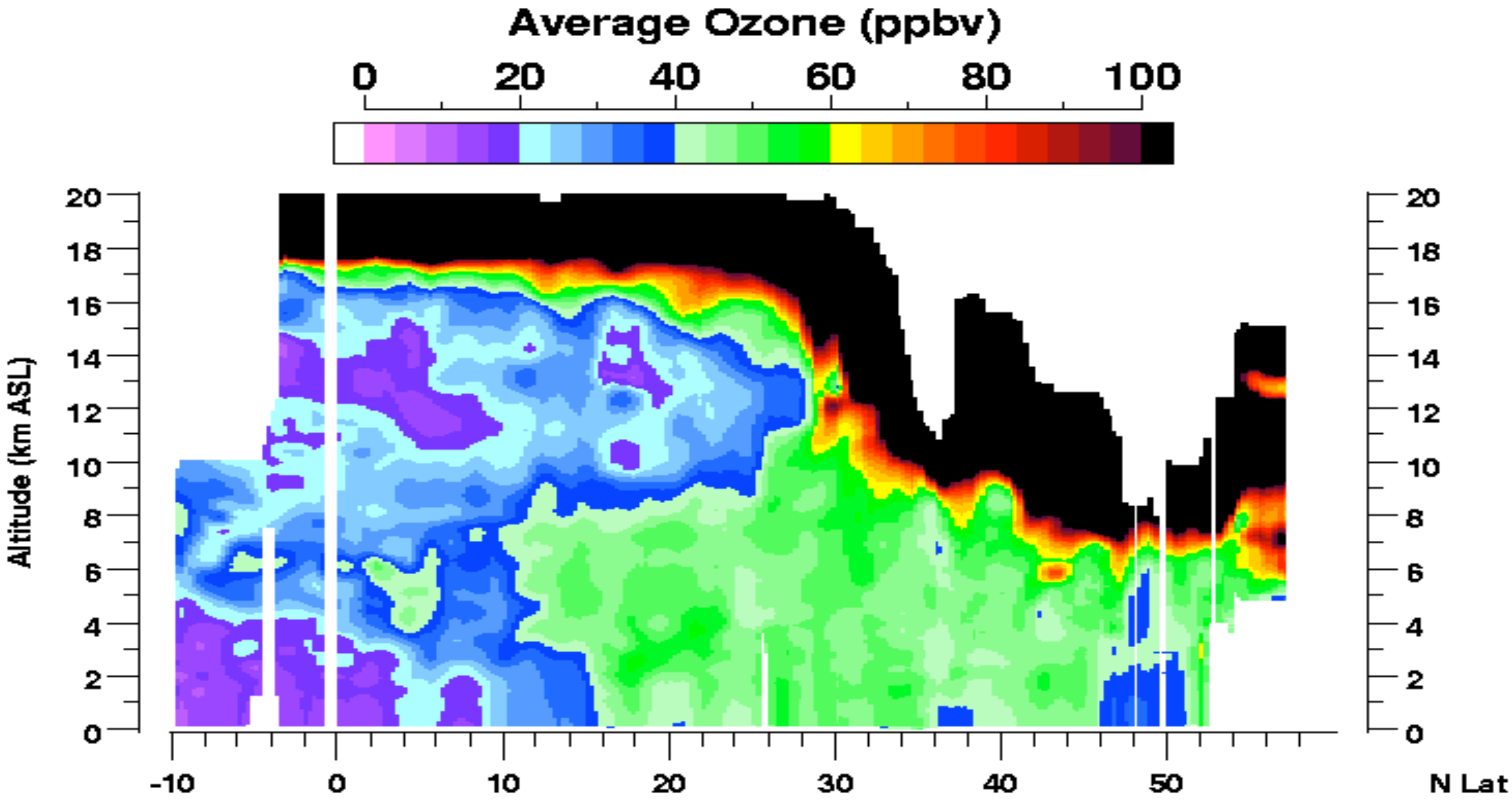
Figure 1. Depiction of regionally polluted (labeled i), Eurasia (labeled ii), Pacific (labeled iii), and Japan regions with examples of 10 days backward isentropic trajectories (clusters of four) arriving in the boundary layer at Sapporo (SAP), Tsukuba (TSB), Kagoshima (KAG), and Naha (NAH). The thick lines within region i show the highly polluted region. Dotted lines show the Japan region. The thicknesses of the trajectories are proportional to the strength of respective pathway, which is also shown as a percentage (e.g., 41/42% indicates 41% for the boundary layer and 42% for the lower troposphere).



Climatology of O3 at two locations in Japan based on radiosonde observations (1970-2002)

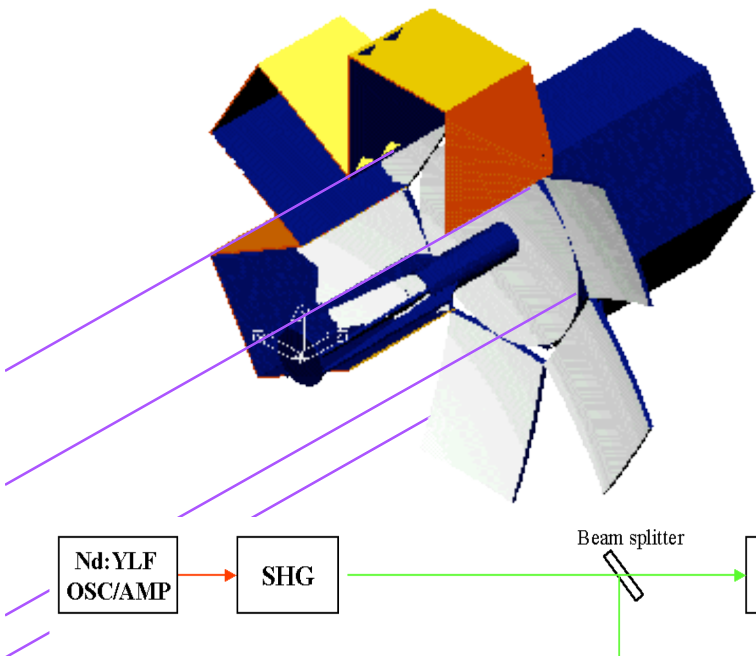
From: M Naja and H Akimoto, JGR (2004)

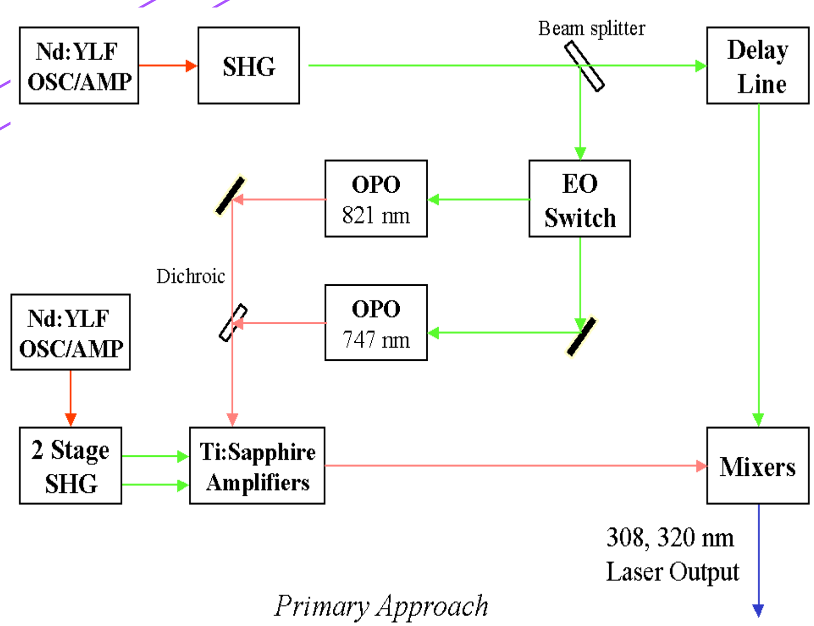
Latitudinal Variation of O_3 over the Pacific Measured by Airborne UV DIAL System in 1991 (NASA PEMW/B)



Browell, Ismail, and Grant (2003)

High Energy, Efficient UV Laser Development for Space applications





Primary Approach

[ORACLE: W. C. Edwards, 1997]

Objective:

Develop and demonstrate necessary laser technology required to achieve defined UV laser transmitter requirements. Single and multiple transmitter approaches and system reliability will also be addressed.

Benefits:

Provided the highest output energy to date for a tunable solid-state UV laser system.

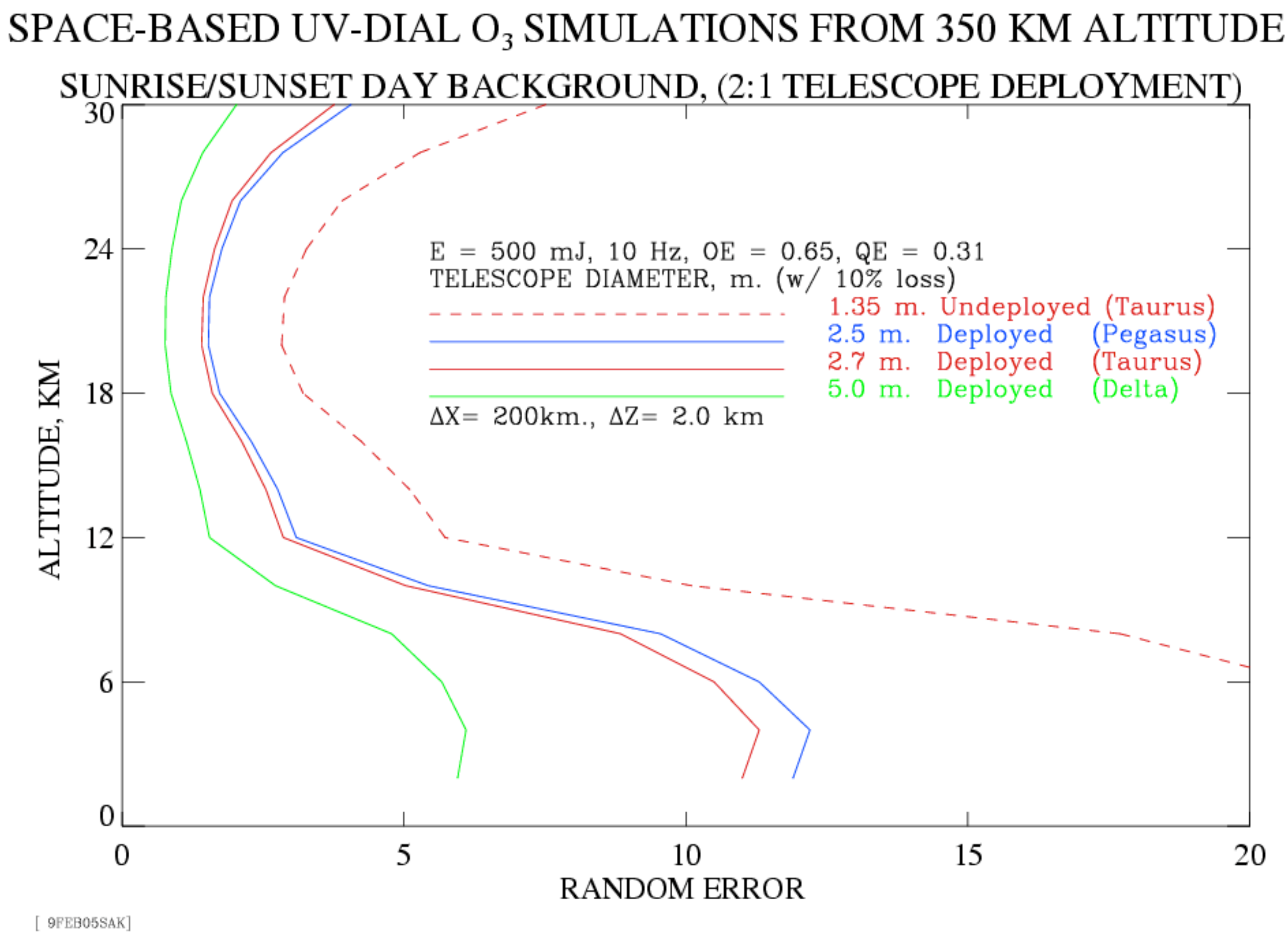
Accomplishment: Produced 150 mJ of energy at 320nm. This output surpasses previous solid-state laser work in the UV by a factor of two.

Results in highest ever electrical to optical efficiency for a solid state UV laser system.

Increases the efficiency of a solid state UV laser system by a factor of four

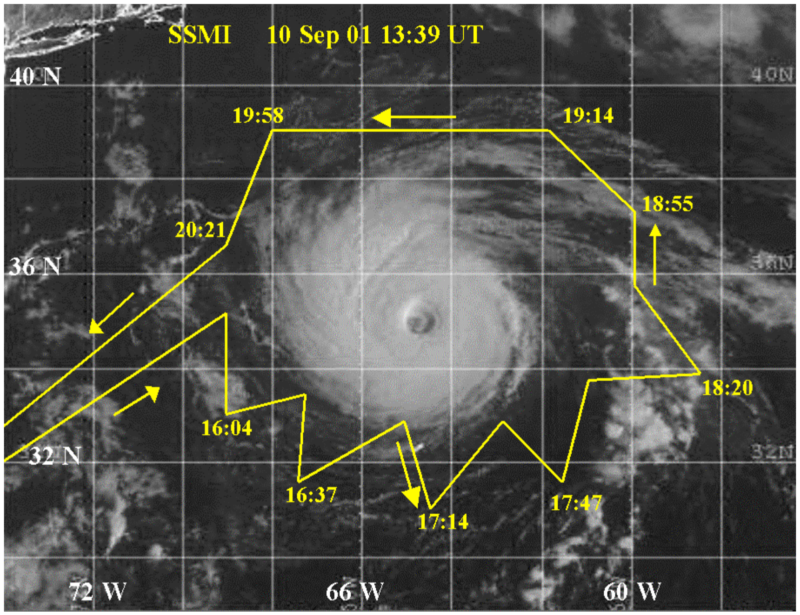
Required Laser Performance

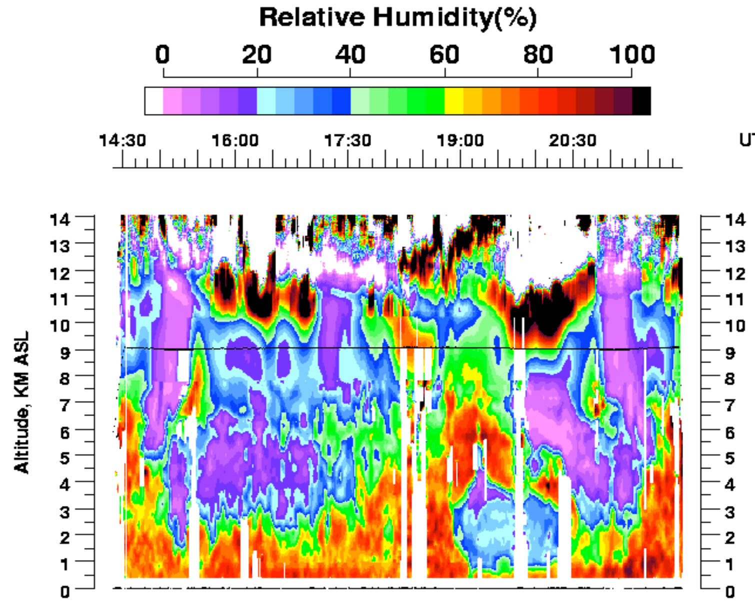
Wavelength	305-308 / 315-320 nm
Linewidth	<50 pm
Energy/pulse	500 mJ
Electrical to Optical Efficiency	>2%
Pulse Width	<20 ns

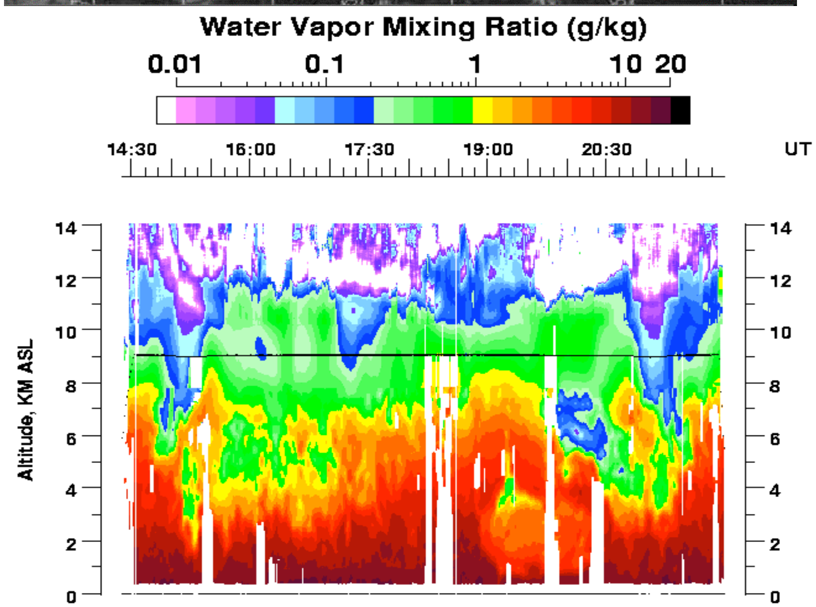


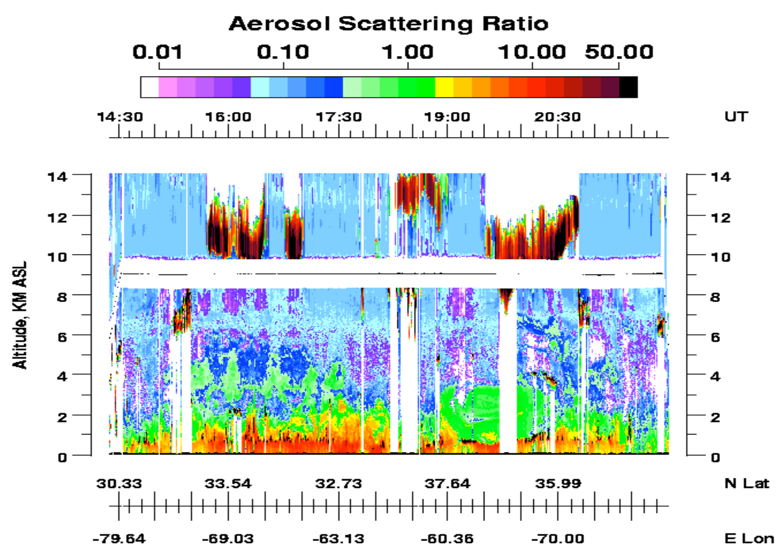
SPACE-BASED UV-DIAL O_3 SIMULATIONS FROM 350 KM ALTITUDE
SUNRISE/SUNSET DAY BACKGROUND, (2:1 TELESCOPE DEPLOYMENT)
E = 500 mJ, 10 Hz, OE = 0.65, QE = 0.31
TELESCOPE DIAMETER, m. (w/ 10% loss)
1.35 m. Undeployed (Taurus)
2.5 m. Deployed (Pegasus)
2.7 m. Deployed (Taurus)
5.0 m. Deployed (Delta)
ΔX= 200km., ΔZ= 2.0 km
ALTITUDE, KM
0
6
12
18
24
30
0
5
10
15
20
RANDOM ERROR
[9FEB05SAK]

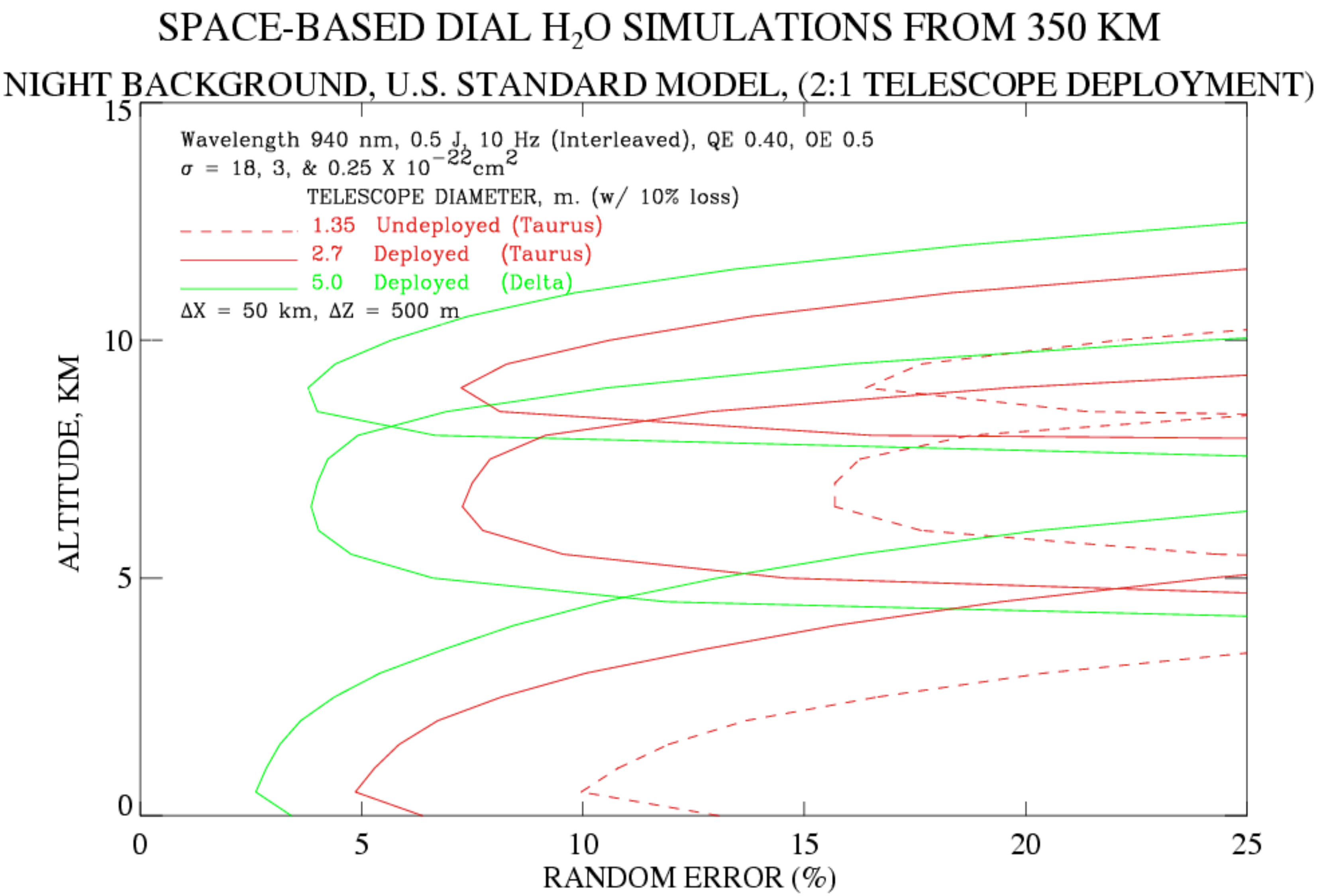
Water vapor DIAL measurements to study impact on hurricanes:
LASE measurements from the NASA DC-8 around Hurricane Erin, Sept. 10, 2001.







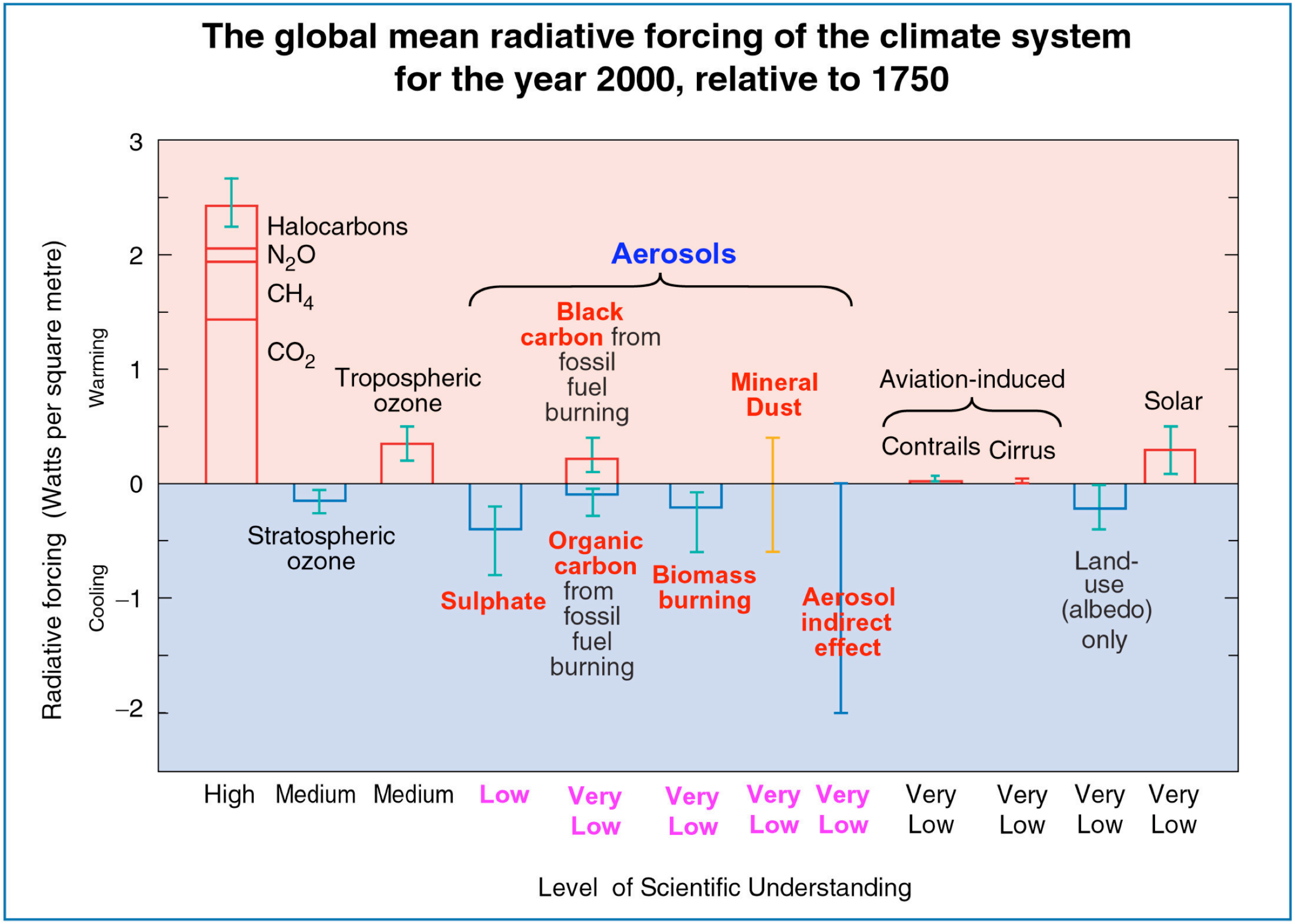




SPACE-BASED DIAL H2O SIMULATIONS FROM 350 KM
NIGHT BACKGROUND, U.S. STANDARD MODEL, (2:1 TELESCOPE DEPLOYMENT)
Wavelength 940 nm, 0.5 J, 10 Hz (Interleaved), QE 0.40, OE 0.5
σ = 18, 3, & 0.25 X 10^-22 cm^2
TELESCOPE DIAMETER, m. (w/ 10% loss)
1.35 Undeployed (Taurus)
2.7 Deployed (Taurus)
5.0 Deployed (Delta)
ΔX = 50 km, ΔZ = 500 m
ALTITUDE, KM
RANDOM ERROR (%)
0
5
10
15
20
25

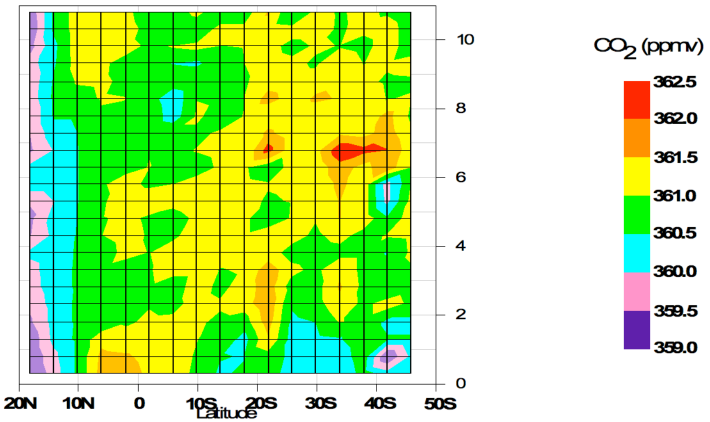
Climate Forcing by Atmospheric Constituents

Computing the net radiative forcing due to anthropogenic changes (IPCC, 2001)

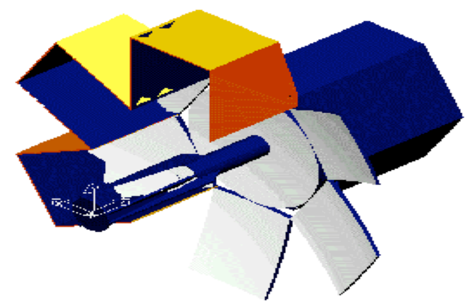


Technology Developments for Space-Based CO_2 profiling

- Important component of Carbon Cycle
- Major cause of climate change
- Global distribution of sources/sinks is uncertain

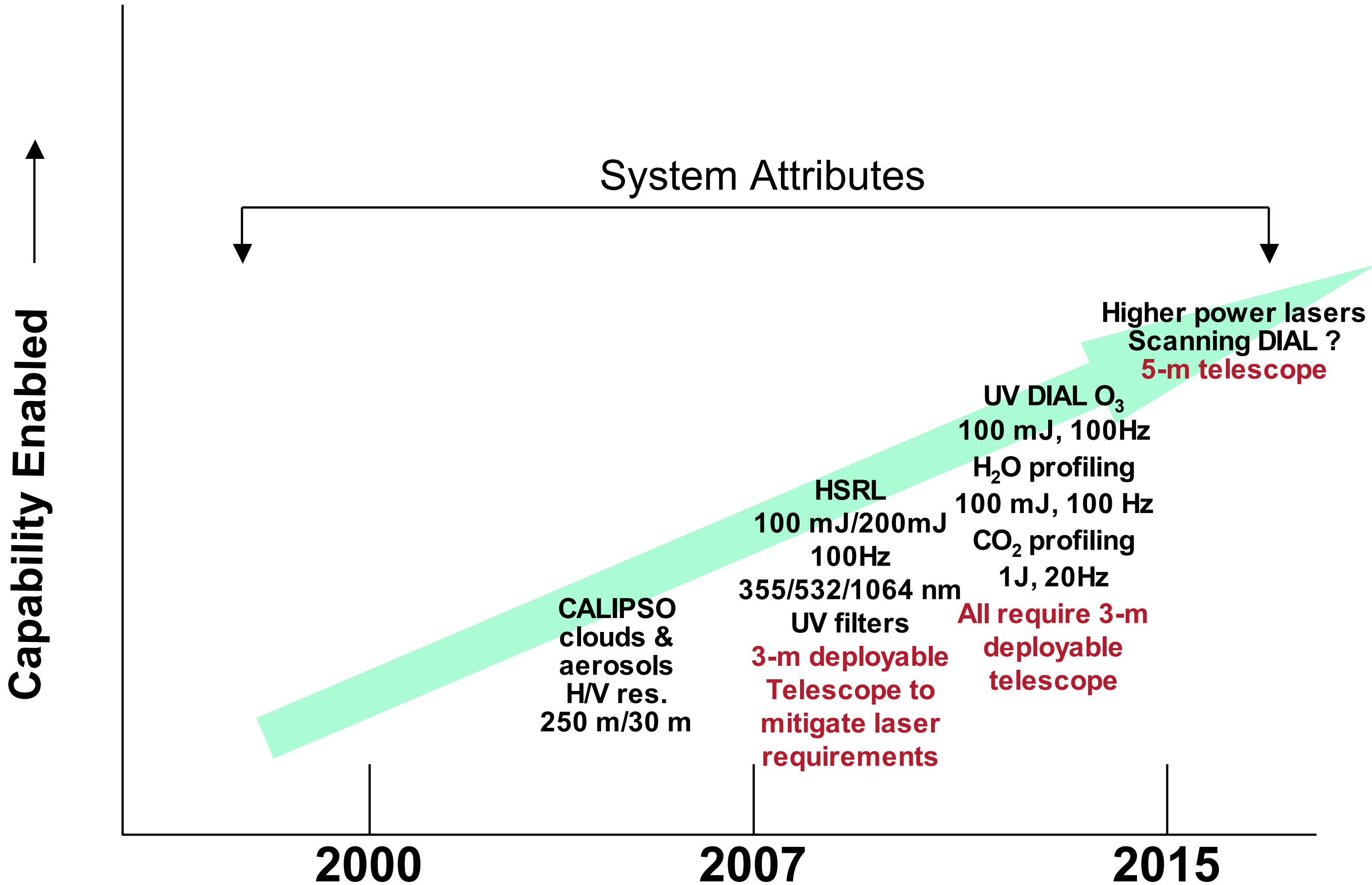


Mean Concentration of CO_2 from in-situ measurements over south Pacific Basin as a function of latitude and altitude, GTE-PEM Tropics-A



- Space-based lidar system:
  - CO_2 global coverage
  - Altitude profiles of CO_2
- CO_2 Lidar approach:
  - 2 micron LLRP technology
  - LASE DIAL techniques
  - Advanced IR detectors
  - 3-m deployable telescope

Technology Roadmap: Aerosol/DIAL Trace Gas Profiling



[Ismail, 2005]

DOME Project Develops Component Technology Leading to a Flight-Ready Instrument Concept

Enables

- Global tropospheric DIAL profiling of O_3, H_2O and CO_2 with day or night coverage, absolute measurements and direct inversion capability

Enhances

- Global scale lidar profiles of aerosol and cloud optical and microphysical properties
- Global wind (direct detection)
- Global oceanographic lidar

Applications

- Better understanding of Earth's atmospheric system
- Improves capability for predicting climate and weather
- Atmospheric composition and dynamics, and air quality
- Water and energy cycle
- Global carbon cycle